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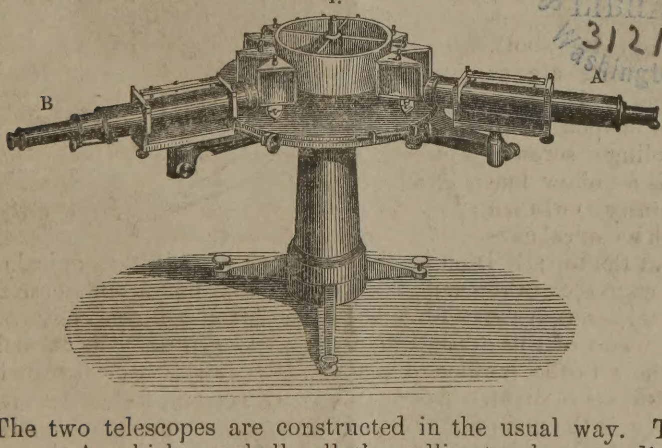
On the Construction of a Spectroscope with a number of prisms, by which the angle of minimum deviation for any ray may be accurately measured and its position in the solar spectrum determined.

BY JOSIAH P. COOKE, Jr.

In an extract from a letter of the author published in this Journal, vol. xxxvi, p. 266, a method of adjusting the prisms of a compound spectroscope was described, by which the adjustment for any portion of the spectrum could be obtained with great rapidity and accuracy. A further study of the subject has shown that the method of adjustment then only briefly described admits of the highest precision, and may be applied to the exact measurement of the angle of minimum deviation of the spectrum rays. It has been thus possible to apply the great dispersive power of the large Cambridge spectroscope in determining the relative position of the various spectrum lines, and to secure all the accuracy of which angular measurements are capable. The value of such measurements is obvious, and with the hope that this method will prove to be an assistance to investigators we propose to give in this paper a description of our instrument and of the manner of using it.

The general construction of the instrument is shown in fig. 1.

1.



The two telescopes are constructed in the usual way. The telescope A, which we shall call the collimator, has an adjustable slit placed exactly at the focus of the object glass. The small tube which carries the slit slides into the body of the telescope, but a rack and pinion motion would be preferable, so that when the focus is changed the slit will necessarily remain vertical. The rays of light diverging from the slit and rendered

parallel by the object glass of the collimator next pass through a series of prisms adjusted around a conical wheel, which will be soon described, and are then received by the telescope B. The spectrum, which is formed at the focus of the object glass of this telescope, is examined with eye-pieces of different magnifying powers in the usual way. The object glasses of the telescopes are $2\frac{1}{4}$ inches in diameter and have a focal length of $15\frac{1}{2}$ inches. They rest in Y's and are provided with spirit levels and adjusting screws. The frames which hold the telescopes are supported on pivots turning in sockets at the ends of two arms connected with the body of the instrument and may be clamped in any position. The arm which carries the collimator is permanently attached to the main iron plate, but the arm, which carries the observing telescope may be moved around the plate.

The details of the construction are shown in fig. 2, which is a section made through one of the legs of the tripod and the movable arm, the telescope with its frame and pivot having first been removed from the socket. (This figure as well as fig. 4 were drawn to the scale of one inch to a foot). The parts are as follows: H is an iron tripod with leveling screws; G is a hollow mahogany column with a conical cavity at the top; F is an iron cone which rests in the conical cavity, supporting the whole body of the instrument and connected by a long iron rod with a clamping screw beneath the tripod. By means of this arrangement the instrument may be turned as a whole in the horizontal plane and the collimator directed to the source of light. Above the iron cone and fastened to it securely is the main circular plate of the instrument, which is 18 inches in diameter and $\frac{1}{2}$ an inch in thickness. Near the outer edge of this plate is inserted a band of silver, which is graduated to 10″ of arc. On the under part of the plate there is a neck and at the center of the upper surface a socket, which are accurately centered with each other and with the graduated limb. Around the neck at E moves an iron collar, to which is attached

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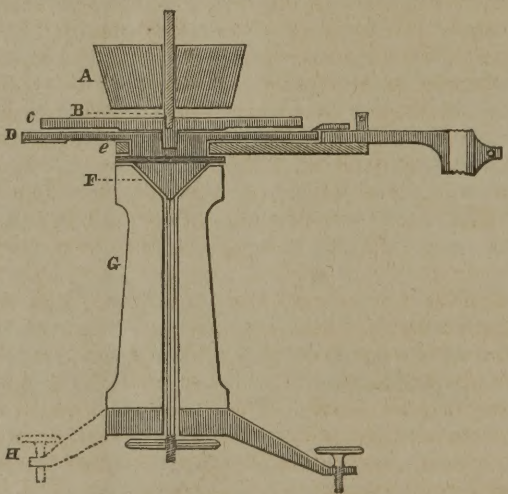
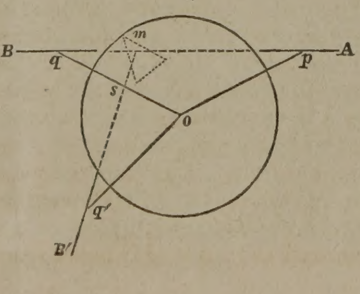


the arm bearing the observing telescope. This moves, therefore, concentric with the graduated limb and bears a vernier by which the angular motion may be determined, reading to 10″. In the socket of the first plate rests the pivot of a second plate, C, which turns on the first and supports the prisms with the adjusting wheel A. The diameter of the upper plate is an inch less than that of the lower plate, so as to expose the graduated arc near the outer edge of the latter, and its upper surface is as flat and even as possible. Rising from the center of the upper plate there is a tall screw pivot of iron, B, on which turns a conical wheel, made also of iron. By this motion the wheel may be either raised or lowered. This wheel is an essential portion of the instrument, and we will next consider the theory of its use.

In the ordinary method of measuring the angle of minimum deviation with a Babinet's goniometer the prism is placed on a revolving plate at the center of the graduated circle, and so adjusted that the edge of the refracting angle shall be perpendicular to the plane of the circle, and its bisectrix parallel with a diameter of the circle. The axis of the collimator and observing telescopes, moreover, being parallel with a diameter of the circle, it is evident that, when the prism and telescope are turned into the position of minimum deviation, the vertex of the angle of minimum deviation will coincide with the center of the circle, and hence the arc intercepted between two radii of the circle parallel to the axes of the two telescopes will be the measure of the angle required. This angle is practically measured by first bringing into line of collimation the observing telescope and collimator, so that the image of the slit at the end of the collimator coincides with the vertical wire in the eye-piece of the telescope. The position of the vernier on the graduated arc is now noted. Then, having adjusted the prism, both the prism and the telescope are turned to the position of minimum deviation, and a coincidence established between the vertical wire and one of the lines of the spectrum. The vernier is now again read and the difference between the two readings is the angle of minimum deviation for the ray corresponding to that line.

3.



It will be obvious however from fig. 3, that it is not necessary for the accuracy of this measure either that the prism should be placed at the center of the circle, or that the axes of the telescope should be parallel to one of its radii. If only the bisectrix of the refracting angle passes through the center of the circle, the prism

may be placed on the outer rim of the plate, and if only the radial arm, which carries the observing telescope, moves concentric with the graduated arc, the axis of the telescopes themselves may make any angle with the radius whatever. Let Op and Oq be two radii of the graduated circle. Let Ap and Bq represent the axes of the two telescopes in collimation and making any undetermined angles with the two radii. Place now a prism at m and turn the radial arm Oq into the position Oq', but without changing the inclination of the axis of the telescope to the arm, and let BmB' be the angle of minimum deviation. Since now the two triangles qsm and $q'so$ are similar, it is evident that the angle BmB' is equal to the angle qoq', and is therefore measured by the arc intercepted between the radii Oq and Oq'.

In order now to apply this principle in the spectroscope the glass prisms were mounted permanently in brass frames. The frames rest on three brass pins which were adjusted by filing until the refracting edge of the prism was perpendicular to the iron place C fig. 2. Two brass pins were also attached to the back of each prism and the lengths of these so adjusted that, when the prisms are pushed against the conical wheel, the bisectrix of the refracting angle should coincide with a radius of the wheel. The last adjustment was made with the aid of a guage cut from a sheet of tinned iron fitting at the same time the periphery of the wheel and the face of the prism, which was applied alternately on either side. The angle of minimum deviation of the ray D was then measured for each prism in the following way:—

The prism having been placed on the plate with the pins applied to the periphery of the wheel, the collimator was turned on its pivot, and at the same time the plate C turned on its center, until on applying the eye at the open slit and looking through the object-glass towards the prism, the further back edge of the prism, seen through the glass of the prism, appeared to coincide with the nearer back edge seen directly. When this is the case it is evident that the rays of light which reach the eye from the further back edge of the prism must pass through the glass parallel to the back edge of the prism, or, what amounts to the same thing, perpendicular to the bisectrix of the refracting angle, and when the light passes in this way the prism is at the angle of minimum deviation. When the prism was thus placed the collimator was turned slightly on its pivot until the axis of the telescope prolonged passed through the center of the prism-face, and was then securely clamped in this position. This adjustment may be made with sufficient accuracy by the unassisted eye. The prism having now been turned one side, the arm of the observing telescope was turned on its center, and at the same time the telescope turned on its pivot until it came into exact collimation with

the collimator. In order to facilitate this adjustment the telescopes are provided with caps which cover the object-glasses of the telescopes with the exception of a narrow vertical slit at the center. The pivot of the observing telescope was next clamped and the caps having been removed the image of the slit seen through the observing telescope was brought into exact coincidence with the vertical wire and the position of the vernier noted. The prism was now brought back to its place by turning the upper plate of the instrument, and the observing telescope also turned until the position of minimum deviation for the ray D was attained and this well known double line brought to coincide with the vertical wire. The limb was then again read, and the difference of the two readings gave the angle of minimum deviation for the prism.

In order to show that this method of measurement is perfectly accurate, we give below the angles of minimum deviation of the nine prisms of the Cambridge spectroscope measured as just described, and in a parallel column the same angles measured in the old way with the prisms at the center of the plate. It will be seen that the differences are insignificant and within the limits of error of observation:

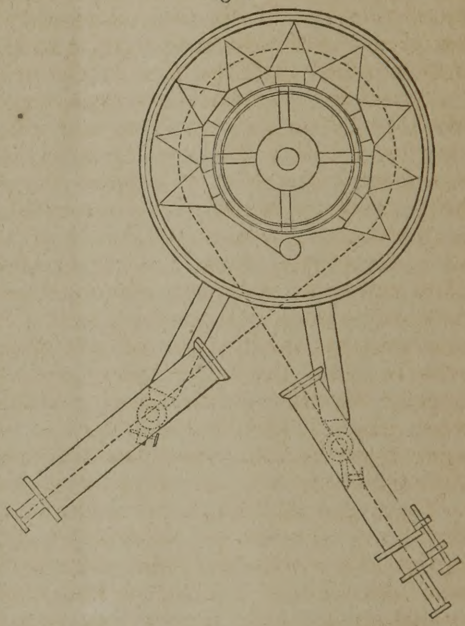
	Measured at center of plate.	Measured on edge of plate.	
No. 1,	29° 31′ 10″	29° 31′ 10″	
No. 2,	29° 29′ 10″	29° 29′ 10″	
No. 3,	29° 28′ 10″	29° 28′ 10″	
No. 4,	29° 37′ 0″	29° 36′ 40″	−20″
No. 5,	29° 28′ 30″	29° 28′ 40″	+10″
No. 6,	29° 36′ 30″	29° 36′ 10″	−20″
No. 7,	29° 28′ 10″	29° 28′ 10″	
No. 8,	29° 29′ 30″	29° 29′ 40″	+10″
No. 9,	29° 28′ 40″	29° 29′ 40″	
	267° 37′ 50″	267° 37′ 30″	−20″

Although the adjustments required may appear complicated, they can be made in far less time than it has taken to describe the method.

It is a well known fact that when a beam of homogeneous light passes through a prism at the angle of minimum deviation the incident and emerging pencils make the same angle with the faces of the prism, at which they respectfully enter and leave the glass. Hence a second prism like the first stands in the same relation to the emerging beam in which the first stands to the incident beam. If then, after the first prism has been adjusted at the angle of minimum deviation a second prism be applied against the wheel at the side of the first, by moving the prism slightly to one side or the other, it will be easy to find a position, in which this prism also is at the angle of minimum devia-

tion, moving of course the prism on the plate without disturbing the position of the plate itself. In like manner other prisms may be added until the required number is obtained. (In the Cambridge spectroscope there are nine glass prisms of 45°, as shown in fig. 4.) This adjustment has only to be made, however, once for all, since when the prisms are adjusted they are fastened to a very thin, flexible brass ribbon, which, passing through a box at the back of each prism, is there secured by clamping screws. The ends of this ribbon, moreover, are attached to a small brass drum, which, being wound up by an ordinary clock spring, draws the chain of prisms tightly around the conical wheel, and keeps them always in place. By tracing the path of a ray of homogeneous light through a series of similar prisms, as is shown in fig. 4, it will be found that the path of the ray within the prisms is always tangent to the same circle, provided that it passes through all under the conditions of least deviation. Assuming, then, that the distances between the prisms are invariable, as they must be when the prisms are fastened to a brass ribbon as just described, it will be evident from a moment's reflection that the greater the refrangibility of the given ray the less must be the diameter of the circle, around which the prisms should be arranged in order that the ray may pass under the required conditions, and, knowing the dimensions of the prisms as well as the index of refraction and dispersive power of the glass, it is easy to calculate approximatively what the diameter should be in a given case. The dimensions of the conical wheel A, fig. 2, were thus determined—the largest diameter, 9½ inches, corresponding to the extreme red, and the smallest diameter, 8½ inches corresponding to the extreme violet rays of the solar spectrum. In order to facilitate the adjustment a series of lines were engraved encir-

Fig. 4.



cling the wheel at equal distances from each other and numbered from 1 to 12.

Having described the construction of the instrument it will now be easy to understand the method of using it. Let us suppose that the object is to measure the angle of minimum deviation of the blue ray of the strontium spectrum. By examining any chart of the spectra of the chemical elements it will be found that this line is situated roughly at somewhat less than two-thirds of the distance from A to H. If, then, we turn the conical wheel until the pins of the prisms all rest against the line marked 7, we shall have approximatively the true position. We then adjust the collimator with reference to the first prism exactly as before described for a single prism. Turning then the upper plate so as to remove the prisms out of range, we bring the observing telescope into collimation with the collimator, as also before described, when on reading off the limb we have the starting point for our measure. We next turn the plate and move the telescope until the spectrum appears in the field, and carefully bring the blue line to coincide with the vertical wire at the position of minimum deviation. We now raise or lower the conical wheel and notice if in this way the angular deviation is diminished, and leave the wheel in the position where the minimum is reached. It now only remains to again read the limb when the difference of the two readings subtracted from 360° will give the angular deviation required.

When near the position of minimum deviation a large motion of the conical wheel produces only a slight motion of the image, so that after a table has been made giving the position of the wheel for a few of the marked lines of the spectrum it is always possible to bring the wheel at starting to the desired point. Moreover, the fact that when near the position of minimum deviation the position of the image is affected so slightly by a small change in the position of the prisms, renders it possible to make all the adjustments required with exceeding rapidity and accuracy.

In order to test the accuracy of our method we have made several determinations of the minimum deviation of the line D, and although between each determination the whole apparatus was completely dismounted, the value obtained was in all cases 267° 37′ 50″.[1] It will be remembered that the sum of the angles measured on each prism separately at the center of the plate, as given on page 309, is precisely the same (267° 37′ 50″) and the sum of those measured on the edge of the plate (267° 37′ 30″) only differs from this by 20″.

When it is not important to use absolutely the whole aperture of the prisms it is not necessary to change the position of the collimator in passing from one part of the spectrum to an-

[1] As the mean of the two lines.

other. If we adjust the collimator as above described, when the prisms rest against the middle circle on the wheel, the whole spectrum can be passed under review with great rapidity without any further change of the collimator, and each point seen under the condition of minimum deviation. When, however, on account of the feebleness of the light it is important to use the whole aperture of the prisms, a slight gain can be obtained by readjusting the collimator at the extreme points of the spectrum. In making the measurements described in this paper, an important advantage is gained in keeping the position of the collimator fixed; for if its position is changed, the point to which the angular measurements are referred is changed also, and must be determined anew. If however the arms, to which the telescopes are attached, are so arranged with a sliding motion that both the collimator and the observing telescope may be moved parallel to themselves without altering their relative angular position, the whole aperture of the prisms may at any time be used, and nevertheless all the measurements referred to the same point on the graduated limb.

Besides the set of glass prisms the Cambridge spectroscope is also provided with a set of sulphid of carbon prisms, which have been previously described in this Journal. They are mounted on a separate plate with a separate wheel of the proper dimensions and are arranged in all respects like the glass prisms above described. The plates are provided with handles so that one battery of prisms may be quickly lifted off from the instrument and the other put in its place. But although the liquid prisms are valuable on account of their great dispersive power in bringing out faint lines, especially in the more luminous portions of the spectrum, yet their use is very restricted. One difficulty arises from the immensely rapid change of the index of refraction of sulphid of carbon with the slightest change of temperature. We have noticed within half an hour on a summer's day a change of 8′ in the angle of minimum deviation of a single sulphid of carbon prism of 45°, although the temperature of the room had only in the meantime changed eight tenths of a Centigrade degree. The temperature of the prism undoubtedly changed much more than this; but when we remember that the variation thus produced would amount to over one degree for the nine prisms, it will be seen that they must be useless for any purposes of direct measurement. Again, sulphid of carbon is far less transparent than glass to the more refrangible rays of the spectrum, and lastly, a slight change of temperature in the observing chamber produces at once currents in the liquid, which are fatal to good definition. Nevertheless under the best conditions, we have found that sulphid of carbon prisms define as well or even better than glass. The instrument

described in this paper, with the exception of the glass prisms, was made by Messrs. Clark & Sons of Cambridgeport, and we would here especially express our indebtedness to Mr. George Clark for his great ingenuity in planning and executing the mechanical details. We reserve for another article an account of the results of our measurements.